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Analysis of Industrial Waste Quality Control Using Generalized Variance and Hotelling's T^2 Control Diagram Methods

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ABSTRACT

Environmental pollution is an unsettling problem for everyone and the ecosystem which can be caused by poorly managed waste originated from the final output of industrial production processed. It can negatively impact the surrounding environment if it is not handled properly. Therefore, the waste must be processed until it meets the predetermined characteristic standards before being disposed of. Among the actions that can be taken is carrying quality control. This study aims to evaluate and characterize the quality of the waste produced. The methods used were the generalized variances and Hotelling's T^2 control charts. The data used for this research was the characteristics of liquid waste from a sugar factory industry, taken from May to September 2023. The quality control results, which were obtained using the generalized Variance control chart, could be statistically controlled after eight improvements. Then, Hotelling's T^2 control chart was successfully controlled after one test. The capability index value obtained was > 1, indicating that the quality control process in liquid waste at the Pesantren Baru sugar factory is capable or controlled.

1. Introduction

An industry is a company or activity that processes raw materials into finished goods with added values to make a profit [1]. Due to this goods production, industrial waste can potentially pollute the environment. This pollution occurs when industrial waste is released into the environment without proper treatment. If this constantly happens, it can negatively impact the environment, cause health problem, and damage the ecosystem [2]. In addition, waste disposal can cause pollution to both aquatic and terrestrial ecosystems due to the high content or organic matter in waste, which can have negative impacts on the environment if disposed directly [3].

Industrial waste can be the result of production process activities. One sector that can produce such waste is the food industry, one of which is the sugar industry. One of the problems in the industry involves the discharge of liquid waste [4]. Indonesia has many sugar factories including Pesantren Baru Sugar Factory, which is located in Pesantren District, Kediri. Due to its proximity to a densely populated settlement, this factory brings negative impacts to the surrounding communities' health and triggers pollution [5]. For instance, in 2018, residents' water sources were polluted, allegedly due to waste produced by the Pesantren Baru Sugar Factory. This problem occurred in Pesantren Village, Kediri City, where residents experienced difficulties in accessing clean water due to pollution caused by waste disposal from the sugar factory [6]. Hence, this case highlights the need to properly handling liquid waste from sugar factories, as prolonged negligence can led to environmental pollution [7]. Handling of industrial waste can be done by managing liquid waste using processing using suspended culture, biological processes with attached culture, and processing with a lagoon or pond system. Liquid waste handling has several criteria that must be adhered to during the process, including pH, biological oxygen demand (BOD), chemical oxygen demand (COD), oil and fat, and Sulfide. The goal is that the waste can be processed to the next stage [8].

Before liquid waste is discharged into water bodies or rivers, it must first undergo a treatment procedure as regulated by the government. The policy mandates that every industry must comply with wastewater quality standards, thereby requiring the quality control of liquid waste to maintain the quality of the waste [9]. Quality control can be done using the statistical process control (SPC). SPC is a method that analyzes process performance with statistical techniques to reduce deviations or errors, evaluate process capability, and establish relationships between existing concepts and techniques to make process improvement [10]. Quality control can be done by making control charts, one of which can be done with generalized variance and Hotelling's T^2 control charts [9].

A control charts is a tool used to monitor the quality of a process or activity whether it is under statistical quality control or not. The quality of a product can be determined by the interaction of several correlated characteristics [11]. There are two types of control charts that can be used in process control: attribute control and variable control charts. Attribute control charts aim to control processes measured on a discrete scale, while variable control charts are useful for measuring process parameters and product characteristics on a continuous scale [12].

Variable control diagrams are divided into two types based on the number of variables used: univariate and multivariate variable control charts. Control charts that apply to data with one characteristic are called univariate, while multivariate variable control chart are for data with two or more characteristics. Types of multivariate control charts include the generalized variance ($|S|$) and the Hotelling's T^2 control chart [13]. The generalized variance control chart is used to assess the variability of product quality, while the Hotelling's T^2 control chart is used to evaluate quality based on the quality characteristics of the product [14].

The use of multivariate control charts such as generalized variance and Hotelling's T^2 provides a comprehensive approach to monitoring the quality of industrial wastewater by considering the interrelationships among multiple quality characteristics. These methods enable industries to detect process deviations more effectively and maintain compliance with environmental regulations. Therefore, this research focuses on analyzing industrial waste of Pesantren Baru Sugar Factory quality control using generalized variance and Hotelling's T^2 control charts as tools to enhance the reliability and effectiveness of wastewater monitoring processes.

2. Method

2.1. Related Works

Previous studies have applied the generalized variance and Hotelling's T^2 control charts. A study employed Hotelling's T^2 control charts on wastewater treatment using BOD, COD, total suspended solid (TSS), total ammonia, sulfide, and pH parameters. The results indicated that the value of the upper control limit (UCL) was 24.51, with two points detected were outside the control [15]. Other research was conducted using the generalized variance and Hotelling's T^2 control charts to determine whether the quality of wheat flour characteristics was under control [16]. The results indicated that, even after applying the generalized variance control chart, the process remained statistically uncontrolled and required another improvement. Similarly, after applying the Hotelling's T^2 control, the process was still not under control. After the improvement was made, the process capability value was obtained, suggesting the three quality characteristics that had been determined in the observation

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data on wheat flour was not suitable or capable of meeting the specified limits that had been set [16]. Other research used Hotelling's T^2 control chart on the diesel engine cylinder lubrication. The results indicated the presence of out-of-control values, so the lubrication process on marine diesel engines must be improved. Optimal results were obtained or controlled after improvements were made [17].

2.2. Dataset

This study used secondary data obtained from the results of wastewater treatment tests at the Pesantren Baru Kediri Sugar Factory in the 2023 milling process period, namely from May to September. The parameters used in this study included pH, BOD levels, COD levels, TSS, oil and fat, and sulfide. Each variable had a specification limit according to the predetermined provisions, the specification limit for each variable can be seen in Table 1.

Table 1. Table Type Styles

Parameters	Specification Limits	Units
TSS	150	Mg/L
pH	6-9	-
BOD	75	Mg/L
COD	150	Mg/L
Oil and fat	5	Mg/L
Sulfide	0.002	Mg/L

2.3. Research Stage

The stages or sequence carried out in this study is described in a flow chart presented in Fig. 1.

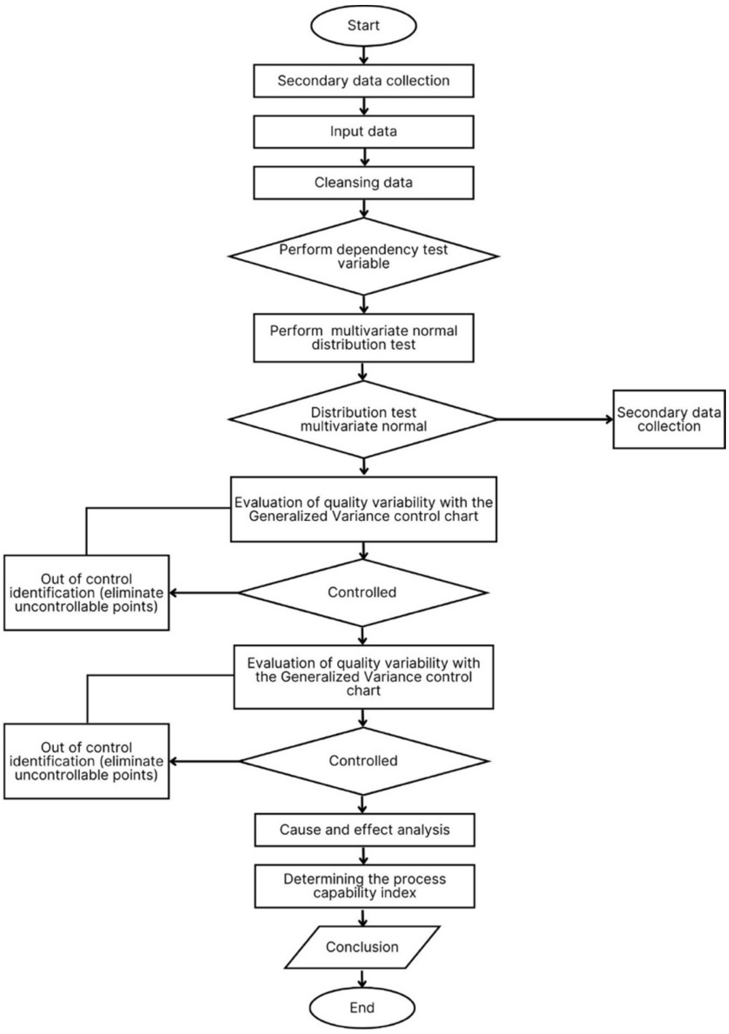

Fig. 1 Research flowchart.

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2.4. Statistical Quality Control

2.4.1. Generalized Variance

Generalized variance control charts are one of the methods used to control the process of multivariate data. In addition, it is also useful in monitoring or controlling process variability to stay within the desired limits [18]. The basis of the generalized variance control charts is the generalization of the sample variance, used as the determinant of the sample covariance matrix, to measure multivariate expression [16]. In a generalized variance control chart, the mean $E|S|$ and variance $V|S|$ are used and have the interval $E|S| \pm \sqrt{V|S|}$. The values of $E|S|$ and $V|S|$ can be obtained using $E(|S|) = b_1|\Sigma|^2$ and $V(|S|) = b_2|\Sigma|^2$ [19].

The generalized variance control charts can be obtained by looking at the control limits that have been obtained. The following is the control limit formula in the generalized variance control charts.

$$UCL = |\Sigma|(b_1 + 3\sqrt{(b_2)}) \tag{1}$$

$$CL = b_1|\Sigma| \tag{2}$$

$$LCL = |\Sigma|(b_1 - 3\sqrt{(b_2)}) \tag{3}$$

In practice, the covariance matrix S is used to estimate the value of Σ based on the previous sample analysis. If this is the case, then the $|\Sigma|$ values at the UCL, center line (CL), and lower control limit (LCL) can be changed with $|S|/b_1$.

2.4.2. Hotelling's T^2

Montgomery defines Hotelling's T^2 as a control diagram used to monitor and control processes on quality characteristics with more than one inspection process. Hotelling's T^2 control charts are employed when the characteristics are interconnected or dependent. The process of making a Hotelling's T^2 control diagram is divided into two stages: stage I and stage II. In stage I, it can be used to determine control, i.e. test the controlled process by describing m subgroups and calculating the sample statistics S and $\bar{\bar{x}}$. In stage II, it can be used to determine the average change [19]. Equations (4) until (7) are the definition of control limits for stage I.

$$UCL = \frac{p(m-1)(n-1)}{mn-m-p+1} F_{\alpha.p.mn-m-p+1}. \tag{4}$$

$$LCL = 0,\ because\ T^2 \geq 0\ (never\ negative). \tag{5}$$

Then, for the upper control in stage II can be given by the following formula.

$$UCL = \frac{p(m+1)(n-1)}{mn-m-p+1} F_{\alpha.p.mn-m-p+1}. \tag{6}$$

$$LCL = 0,\ because\ T^2 \geq 0\ (never\ negative). \tag{7}$$

2.4.3. Ishikawa Diagram

Ishikawa diagram or fishbone diagram is discovered by a Japanese professor named Dr. Ishikawa. Ishikawa diagram is a tool that helps to find the root cause of a problem [20]. Based on the category, it is divided into 5M+E, namely man, machine, material, method, measurement, and environment. Each of these categories has subcauses that need be further broken down [21]. Followings are the steps in preparing the Ishikawa diagram.

a. Identification of significant issues.
b. Identify the elements that cause or result in the problem.
c. Write a list of the main influencing causes.
d. List the secondary causes that impact the primary causes.

2.4.4. Process Capability Analysis

Process capability analysis is a method used to assess the ability of a process to meet the standard requirements of a predetermined product. The purpose of the analysis is to assist in the development of production by reducing or eliminating the variability that occurs in the process [22]. Additionally,

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process capability analysis has another purpose: to select the most suitable process with existing tolerance limits. The process capability value can be found using (8) [23].

$$Cp = \frac{K}{\chi^2_{\alpha.df}}\left(\frac{(n-1)p}{s}\right)^{\frac{1}{2}}. \quad (8)$$

With the interpretation of Cp in mind, several conditions must be considered. The provisions are, if $Cp \geq 1$, the production process has high precision and can be said to be capable or running well. Meanwhile, if $Cp < 1$, the production process has a low precision and can be said to have not yet been capable.

3. Result and Discussion

3.1. Multivariate Assumption Test

This study had two requirements that must be met before conducting multivariate analysis, namely testing multivariate assumptions, which included a dependency test and a multivariate normal distribution test.

3.1.1. Variable Dependency Test

The variable dependency test was conducted to identify the relationship between effluent quality characteristics. Tests to determine the correlation between variables can be done using the Bartlett's analysis. The following hypothesis was used in the variable dependency test:

- $H_0 : \rho = 1$ (there is no correlation between the variables TSS, pH, BOD, COD, oil and fats, and sulfide)
- $H_0 : \rho \neq 1$ (there is a correlation between TSS, pH, BOD, COD, oil and fat, and sulfide)

Furthermore, the results of the calculation using the Bartlett's test are presented in Table 2.

Table 2. Bartlett Test

Bartlett Test of Sphericity		
Approx Chi Square	*df*	*p-value*
464.355	15	0.000

Based on the Bartlett test of independence, the p-value was 0.000, which is less than the significance level of 0.05. In addition, the chi-squared value indicated $\chi^2_{score} = 464.355$, with an degree of freedom 15, while the value of $\chi^2_{table} = 24.996$. This result suggests that the value of $\chi^2_{score} > \chi^2_{table}$. Therefore, the null hypothesis was rejected. This result suggests that there is a relationship between the effluent quality characteristics variables (TSS, pH, BOD, COD, oil and fat, and sulfide). Hence, results can be analyzed using a control diagram.

3.1.2. Multivariate Normality Test

To determine whether the distribution of effluent quality characteristics is multivariate normally distributed, an examination can be carried out using the Q-Q plot, which can be seen in Fig. 2.

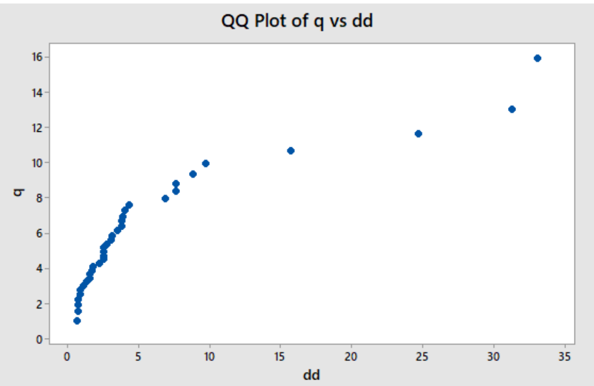


Fig. 2 Q-Q plot of multivariate normality test.

In Fig. 2, the results of the multivariate normality test with the Q-Q plot show that the plots formed are almost close to a straight line. Hence, it can be concluded that the effluent quality characteristics are multivariate normally distributed. Testing can also be done by obtaining the d_{ij}^2 value of all data. The determination is if the number of values $d_{ij}^2 \leq \chi^2_{(p;0,50)}$. The results obtained showed that the t value was 0.74, meaning that the value was more than 50%. It can be concluded that the data on the quality characteristics of liquid waste produced by the Pesantren Baru Kediri Sugar Factory was multivariate normally distributed.

3.2. Generalized Variance

The next step after the multivariate assumption test was to analyze the process variance control using the generalized variance control charts.

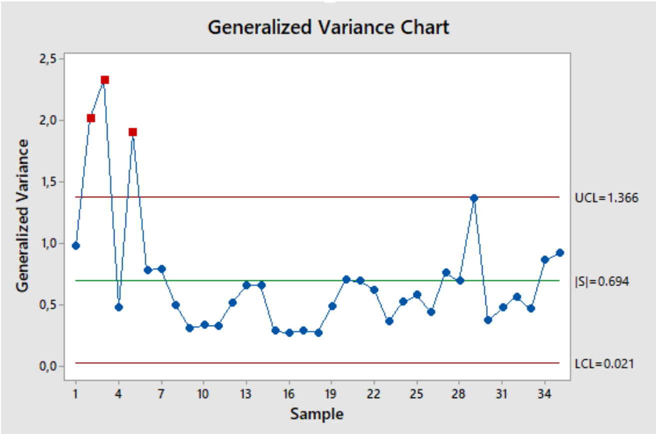
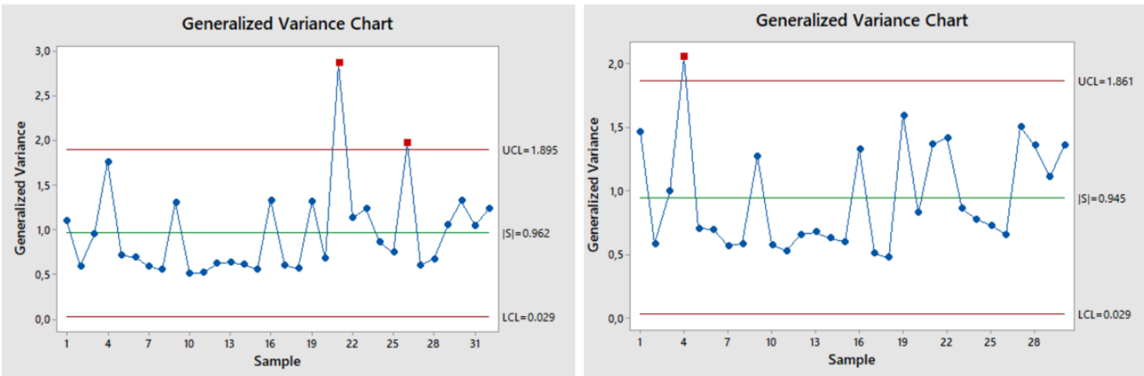


Fig. 3 Generalized variance control chart.

In Fig. 3, the value on the horizontal line indicates the number of observations, while those on the vertical line is the generalized variance plot' value. This study used a total of 35 observations for the generalized variance control chart. Based on Figure 3, the UCL is 1.366 and the LCL is 0.021. In addition, the plots contained in the Generalized Variance control chart above also show that there are observation plots that are outside the control limits, namely the 2nd, 3rd, and 5th observations. So, it can be interpreted that the process variance in liquid waste has not been statistically controlled.

The plots that are outside the control limits need to be corrected by eliminating the out-of-control observations. The results of the new generalized variance control chart after making improvements to observations that were outside the control limits are presented in Fig. 4.



(a) (b)

Fig. 4 Improvement of generalized variance control chart.

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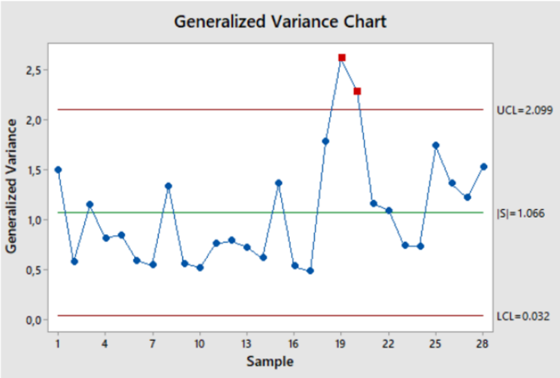

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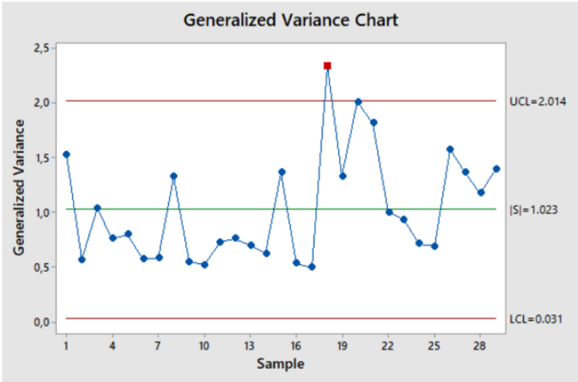
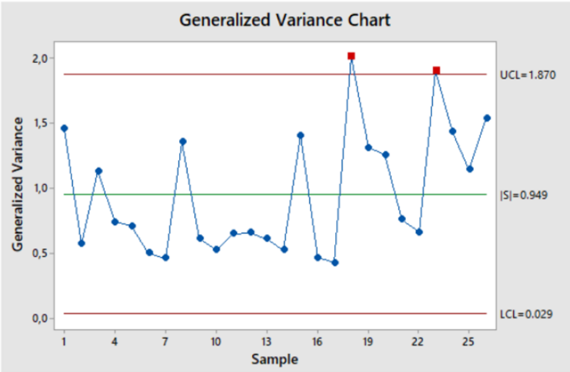


(d)



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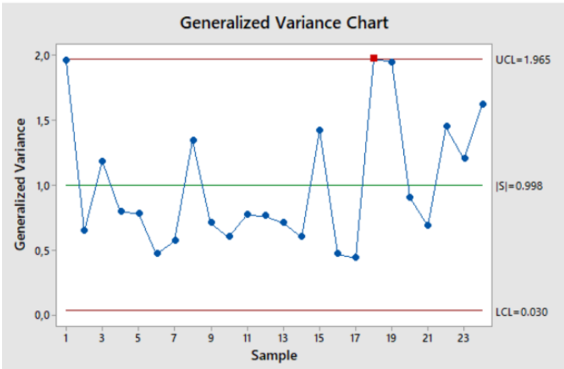
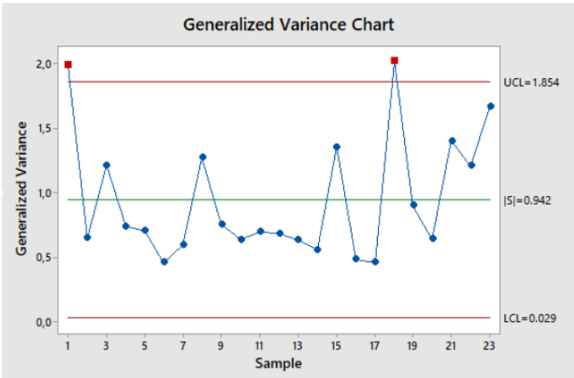


(f)



(g)

Fig. 4 (*Continued.*) Improvement of generalized variance control chart.

After eliminating the out-of-control points for improvement on the generalized variance control chart, the results showed that the process was not yet statistically controlled even after seven times of improvement. In the first improvement, the points that were outside the control limits were the 21st and the 26th observations with, a UCL of 1.99. In the second improvement, it was the 4th observation, with a UCL of 1.86. During the third improvement, the 18th observation was found to be out of control, with a UCL of 2.014. In the fourth improvement, 19th and 20th observations remained outside the control limits, with a UCL value of 2.099.

Then, in the improvement, the UCL value was 1.870 and, in the 18th and 23rd observations, some points remained out of control. Moreover, in the 6th improvement, the 18th observation was outside the control limit, with the acquisition of the UCL value of 1.96. Furthermore, in the 7th improvement, smoe observations remained outside the control limits, namely the 1st and 18st observations, with the UCL obtained is 1.85. Based on the results of the seven improvements on the generalized variance control chart, the process still needs to be improved again.

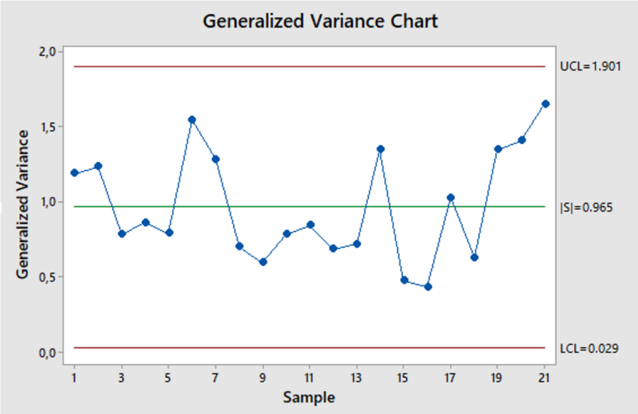


Fig. 5 Controlled generalized variance controlled.

After re-improvement by eliminating the point that was still out of control, the result obtained was the diagram that was already in a controlled state. As evidenced in Fig. 5, no points that were found to be outside the control limits, indicating that the process was statistically controlled, with the obtained upper UCL value of 1.901. Improvements need to be made eight times to get the results of the diagram in a controlled state. Therefore, that after the generalized variance control chart had been controlled, the process could be continued to the subsequent control diagram analysis.

3.3. Hotelling's T^2

Further analysis was carried out using a Hotelling's T^2 control diagram to statistically control the average process in the characteristics of liquid waste of the Pesantren Baru sugar factory. Fig. 6 is the results of the Hotelling's T^2 control chart.

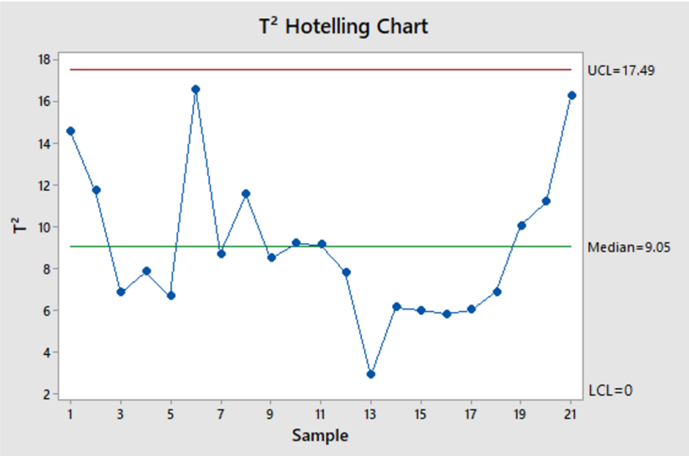


Fig. 6 Hotelling's T2 control chart.

The Hotelling's T^2 control chart obtained a UCL value of 17.49. Meanwhile, the LCL value was equal to 0. In addition, Fig. 6 also shows that there are no observations that are outside the control limits, meaning that the process in the liquid waste of the Pesantren Baru sugar factory for the 2023 milling period is statistically controlled. Since the generalized variance and Hotelling's T^2 control charts were under control, the next process could be continued.

3.4. Ishikawa Diagram

Ishikawa diagrams were used to identify factors that cause the process to be out of control. The results of the Ishikawa diagram can be shown as Fig. 7.

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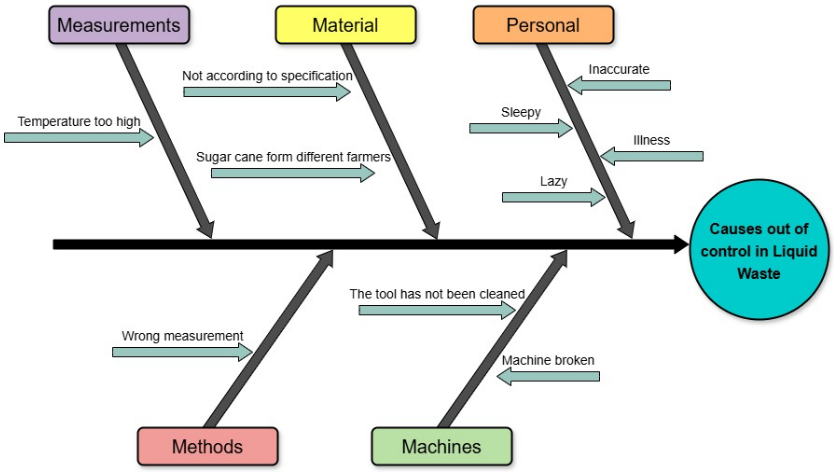

Fig. 7 Ishikawa diagram.

Previously, 14 observations exceeded the control limit. Fig. 7 shows the various factors that led to the uncontrollability of the effluent quality characteristics variable. The first factor comes from a personal perspective, namely due to a lack of thoroughness, sleepy employees, laziness, or because of illness. The second factor is related to machinery, caused by damage to the sugarcane grinding machine. It also occurs because the measuring instrument has not been cleaned, which affects the next process. The third factor is related to materials, namely the sugar cane arrived does not meet the specified specifications. The fourth factor is related to the environment, excessively high temperatures. The last factor is related to methods, which occurs due to errors in measurement.

3.5. Process Capability Analysis

After quality control obtained results in a controlled state, the nest step was to conduct a multivariate process capability analysis. The results obtained were the *Cp* value of 17.40, the process capability index value shows that the *Cp* value is greater than 1. This result indicates that the observed effluent from the Pesantren Baru sugar factory is within the limits of the specifications that have been set. Therefore, it can be said that the process in liquid waste is already in a statistically controlled or capable state.

4. Conclusion

Based on the analysis and discussion conducted using the generalized variance and Hotelling's T^2 control chart methods, the following conclusions can be drawn. The generalized variance control chart required eight improvements before the results obtained were under control. Meanwhile, Hotelling's T^2 control chart only needed one calculation to obtained results that were under control. Furthermore, the process capability analysis result obtained was 17.40. It shows that the *Cp* value is greater than 1, so that the process is capable or already under control according to the predetermined specification limits.

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